

MUSCULOSKELETAL-INDUCED NUCLEATION IN ALTITUDE DECOMPRESSION SICKNESS

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INTRODUCTION

Musculoskeletal activity has the potential to both improve and compromise decompression safety. Exercise enhances inert gas elimination during oxygen breathing prior to decompression (prebreathe), but it may also promote bubble nuclei formation (nucleation), which can lead to gas phase separation and bubble growth and increase the risk of decompression sickness (DCS). The timing, pattern and intensity of musculoskeletal activity and the level of tissue supersaturation may be critical to the net effect. There are limited data available to evaluate cost-benefit relationships. Understanding the relationship is important to improve our understanding of the underlying mechanisms of nucleation in exercise prebreathe protocols and to quantify risk in gravity and microgravity environments. Data gathered during NASA's Prebreathe Reduction Program (PRP) studies combined oxygen prebreathe and exercise followed by low pressure (4.3 psi; altitude equivalent of 30,300 ft [9,235 m]) microgravity simulation to produce two protocols used by astronauts preparing for extravehicular activity. Both the Phase II/CEVIS (cycle ergometer vibration isolation system) and ISLE (in-suit light exercise) trials eliminated ambulation to more closely simulate the microgravity environment. The CEVIS results (35 male, 10 female) serve as control data for this NASA/Duke study to investigate the influence of ambulation exercise on bubble formation and the subsequent risk of DCS.

METHODS

Four experiments will replicate the CEVIS exercise-enhanced oxygen prebreathe protocol, each with a different exception. The first of these is currently underway. **Experiment 1** – Subjects complete controlled ambulation (walking in place with fixed cadence and step height) during both preflight and at 4.3 psi instead of remaining non-ambulatory throughout. **Experiment 2** – Subjects remain non-ambulatory during the preflight period and ambulatory at 4.3 psi. **Experiment 3** – Subjects ambulate during the preflight period and remain non-ambulatory at 4.3 psi. **Experiment 4** – The order of heavy and light exercise employed in the CEVIS protocol is reversed, with the light exercise occurring first (subjects remain non-ambulatory throughout). Decompression stress is assessed with non-invasive ultrasound during each of 14 epochs of a 4 hour simulated spacewalk at 4.3 psi; aural Doppler is used to monitor bubbles (Spencer grade 0-IV scale) passing through the pulmonary artery, and two-dimensional echocardiographic imaging is used to look for gas emboli in the left heart (the presence of which is a test termination criterion). Venous blood is collected at baseline and twice following repressurization to determine if the decompression stress is correlated with microparticles (cell fragments) accumulation. The plan is to test a minimum of 25 and a maximum of 50 subjects in each experiment. A Fisher Exact Test is used to compare test and control groups. Trials are suspended when the DCS or grade IV VGE observations provide 70% confidence of DCS risk >15% and grade IV VGE risk >20%.

RESULTS

A total of 11 Experiment 1 trials have been completed (9 male, 2 female). The observed DCS was significantly greater in Experiment 1 than CEVIS trials (3/11 [27%] vs. 0/45 [0%], respectively, $p=0.03$). Statistical significance was not reached for the increase in peak grade IV VGE (2/11 [18%] vs. 3/45 [7%], $p=0.149$) or cumulative grade IV VGE observations per subject across all trial epochs (8/128 [6%] vs. 26/630 [4%], $p=0.151$). Microparticle data were collected for 5/11 trials (3 with DCS outcomes), showing widely varying patterns that cannot yet adequately be resolved statistically. Following a review of all study data, the data safety monitoring board agreed for Experiment 1 trials to continue with the intent of reaching the planned 25 subject minimum, with any further cases of DCS prompting immediate reevaluation.

DISCUSSION

The results of the Experiment 1 trials support the thesis that decompression stress is increased by ambulation exercise, given the higher incidence of DCS when compared to the non-ambulatory PRP CEVIS trials. Additional Experiment 1 trials may improve the statistical power to assess differences in VGE and to evaluate the relationship between decompression stress and microparticle accumulation. Future experiments will test whether ambulation at altitude during supersaturated conditions generates greater decompression stress than ambulation at ground level

during undersaturated conditions (Experiments 2 and 3) and whether light exercise facilitates the removal of heavy exercise induced nucleation (Experiment 4).